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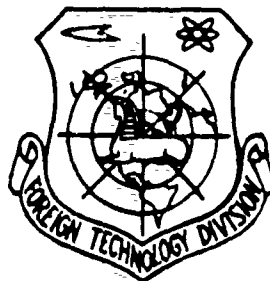


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by

Zhang Xiaoping

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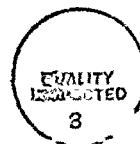
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## LASER APPLICATIONS IN MACHINING SLAB MATERIALS

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Since the invention of the laser back in 1960, laser technology has been extensively applied in many fields of science and technology. There has been a history of nearly two decades of using lasers as an energy source in machining materials, such as cutting, welding, ruling and boring, among other operations. With the development of flexible automation in production, the advantages of laser machining have grown more and more obvious. The combination of laser technology and computer science further promotes the enhancement and upgrading of laser machining and related equipment. At present, many countries are building high quality laser equipment for machining slab materials, such as the Coherent and Spectra Physics corporations in the United States, the Trumpf Corporation in West Germany, the Amada Corporation in Japan, and the Bystronic Corporation in Switzerland, among other companies.

### I. Fundamental Principle of CO<sub>2</sub> Laser Cutting

There are many types of laser: solid-state laser, semiconductor laser, liquid laser and gas laser. The CO<sub>2</sub> laser is one version of the gas laser. Since the CO<sub>2</sub> laser is high in efficiency, large in output power, simple in structure, and relatively low in cost, it is the most frequently used laser in materials processing.

In the case of the CO<sub>2</sub> laser, CO<sub>2</sub> gas is filled in a sealed tube; for better performance, in reality a gas mixture of CO<sub>2</sub>, N<sub>2</sub> and He is used instead. Both terminals of the tube are electrodes; a high voltage zone exists between the electrodes (see Fig. 1). Within the electrical field, electrons are accelerated. In an electron collision process, kinetic energy is released to excite the CO<sub>2</sub> molecules, which are then excited to emit light waves. Light waves alternately reflected between the two reflecting lenses to re-excite light emission, thus forming oscillations as well as light coupling and amplification for the emitting laser.

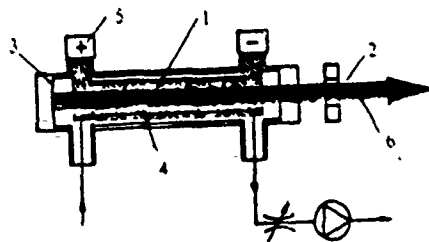


Fig. 1. Operating Principle of CO<sub>2</sub> Laser.  
 Legend: (1) CO<sub>2</sub> gas; (2) Window lens;  
 (3) Reflecting lens; (4) Resonator;  
 (5) Power supply; (6) Laser rays.

A laser generates a type of monochromatic coherent light with very narrow focusing. There can be very high power density at the focus. When a CO<sub>2</sub> laser is used to cut slab materials, the power density may be as high as  $10^8$  W/cm<sup>2</sup>. However, the power density of sunlight at its focus by using a focusing lens is only  $10^3$  W/cm<sup>2</sup>. When a laser is focused on the surface of slab material to be machined, the temperature of a very small surface area of the workpiece rises rapidly at a heating rate as high as  $10^{10}$  °C/s; the temperature gradient thus produced is greater than  $10^6$  °C/cm. The material melts and evaporates at such a high temperature. When the CO<sub>2</sub> laser is used in cutting with the blowing of oxygen, oxygen and the laser beam are coaxially ejected onto the workpiece. On the one hand, a certain

gas pressure assists the cutting process; on the other hand, oxygen serves to assist combustion. Molten slag is generated by high-temperature metal in its combustion in oxygen. The molten slag is oxidized and blown out from the seams being cut. The intensive heat-releasing reaction provides the additional energy to speed up the cutting rate.

## II. Technical Features of Laser Machining of Slab Materials

### 1. High machining quality

Since the focusing capability of a laser is high, its focus can be smaller than 0.1 mm. When slab materials are machined, the width of cut is small, only 0.1 mm. The cut quality is good and is free of any burrs so there is no need for grinding at the next work stage. Laser machining is of the noncontact type, not generating an impact force on the slab material and free of friction and vibration in case of a rigid contact, thus further ensuring machining precision. With laser machining, there are rapid temperature rises and large temperature gradients, thus having very little heating effect near the cut opening. No warped deformation of the slab material results. The relative motion between the optical shaft and the workpiece is controlled by a CNC system with a positional precision of plus or minus 0.1 mm, and a reproducible precision of plus or minus 0.05 mm.

### 2. Good adaptability

Laser machining is a noncontact method that does not use any die. Referring to Fig. 2, many workpieces of complex shapes are difficult to be machined with dies, but these workpieces are readily laser-machined. Laser machining can avoid die machining, manufacture and maintenance, thus saving money and time. The laser beam is praised as a laser cutter with flexible cutting features and capable of grinding forever without turning dull.

Laser machining is most suitable in intermediate and small batches as well as in machining manifold kinds of products, in noncontact machining not only for processing plane slab pieces, but also for machining slab materials of various spatial shapes as shown in Fig. 3.

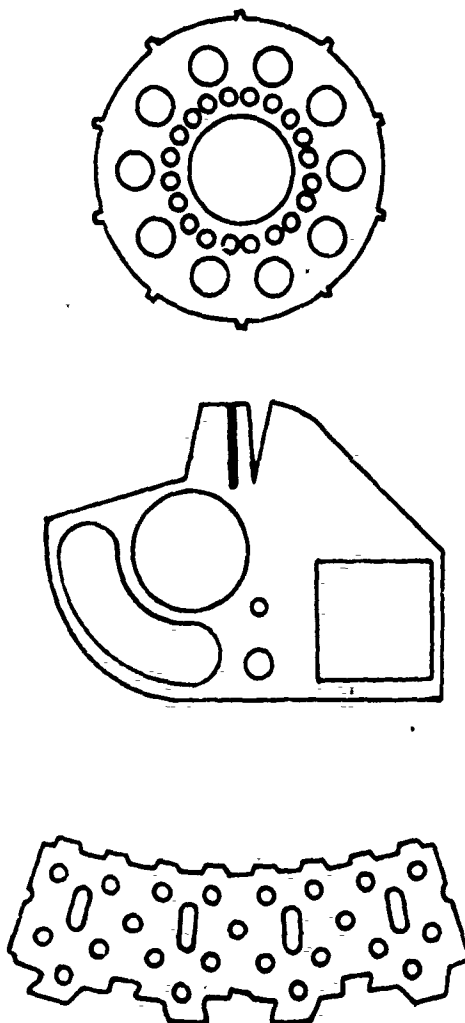


Fig. 2. Complex Shaped Parts  
With Laser Machining.

The adaptability of laser machining is not only manifested in the shapes of parts, but also in the materials that parts are made of. A laser not only can machine metals, but also nonmetals. Of course, since there are different absorbing

capability of a laser used with different materials as well as different optical and thermal characteristics, thus, there are differences in machining among metals. In the case of low thermal conductivity, small temperature coefficient of expansion, and low melting points, temperature, these metals are easily laser-machined; otherwise, metals are difficult to be machined with a laser. For example, metals such as tin, iron, nickel and chromium are easily cut with a laser; however, gold, silver, copper, bronze and aluminum are relatively difficult to be machined. In recent years, Japan and the United States developed machines that use lasers to cut aluminum plates, thus solving the difficult problems of laser machining of aluminum plates. Among nonmetal materials, those with relatively small thermal expansion coefficient are easily machined; otherwise, nonmetals are difficult to be machined. For example, it is easy to use a laser to machine plastics, paper and wood, but laser machining of glass will often lead to breakage.



Fig. 3. Laser Processing of Spatial Shaped Slab Material.

### 3. Easy execution of automation



With electricity and a computer, the performance and machining parameters of a laser beam can be controlled. Furthermore, with a light guiding system and automatic positioning control of the work platform as well as programming of parts processing, an automation complex can be organically formed for the programming of parts to be shaped, determination of parameters and control of processing procedure. As presently made abroad, kW class laser machine tools have relatively popular features of microcomputer control, multiple coordinate motion, reliable performance and convenient operation.

#### 4. Good working environment

There is low noise and little vibration in laser machining; thus, the production environment is good.

#### 5. More flexibility in combination with die machining

Laser cutting has many advantages as mentioned above; however, there are also limitations. For example, some materials are difficult to be machined with a laser; in addition, the cost of laser machining is relatively high. At the Trumpf Corporation in West Germany, laser cutting was combined with die machining in making 180LK and 180LW laser punching machine tools, leading to more flexibility in machining. Lasers are especially used to machine workpieces of complex shape, relatively small dimensions and low batch size, while dies are used to machine workpieces of simple shape, conventional dimensions and large batch size. Materials difficult to be machined with a laser can also be machined with dies. Thus, the productivity and production costs are more scientific and rational.

### III. CO<sub>2</sub> Laser System

Used for slab material machining, this laser machine tool is generally composed of the following components: laser, light guiding system, coordinate work platform, automatic control system and power supply. A laser device is the core of the machine tool.

There are three systems of CO<sub>2</sub> laser devices used in cutting: low-speed axial flow, high-speed axial flow and lateral flow. These flows are distinguished with the included angle between the laser gas flow direction and the direction of emitting laser ray. The axial flow involves the laser gas being coaxial with the direction of the laser beam (Figs. 1 and 4a) while lateral flow is such that the laser gas is vertical to the direction of the laser beam (Fig. 4b).

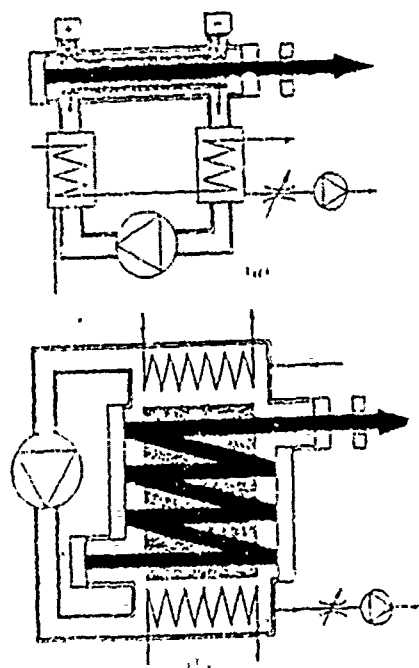


Fig. 4. CO<sub>2</sub> Laser System.  
Legend: (a) High speed axial flow;  
(b) Lateral flow.

Low speed axial flow is an arrangement in which the laser gas flows at low speed passing through a resonator (Fig. 1).

This type of laser is easy to be prepared with flexible adjustment, good stability, convenient maintenance and low price. However, the output power of this kind of laser (1,000 watts at maximum) is lower than in the two other systems.

High speed axial flow is an arrangement in which the laser flows through a resonator at high speed. This type of laser device is high in power, small in size, good in technical features, and high in light quality. The maximum output power may reach 5,000 watts; in addition, the output power can be adjusted.

Lateral flow is such that the laser gas laterally flows through a resonator aided by a lateral direction air blower (Fig. 4b). A reflective lens system can make the laser beam vertical to the gas flow with multiple reflections. The output power of this system is the highest, 25,000 watts at the maximum. However, the stability of the intensity distribution of the emitted laser is affected by the stability of the entire system.

The modes of emitting laser by a laser device can be divided into continuous type, conventional pulse and giant pulse (see Fig. 5).

For continuous wave lasers, its power variation is adaptable to the machining rate. At the beginning of machining, the power increases gradually. When the machining rate is at the maximum, the power also rises to the maximum (see Fig. 5a) in order to ensure the required laser power density. This mode is often adopted when a CO<sub>2</sub> laser device is used to cut conventional carbon steel plates. For a continuous wave laser, its power ranges from 50 to 1,500 watts; these laser devices can be used to cut materials that have a thickness ranging between 0.5 and 10 millimeters; the machining rate is between 0.2 and 20 meters per minute. One shortcoming of this mode is that the persistent

power density can apply too much heat to the metal material, thus causing defects at the cut opening and burrs. In particular, this situation is likely to occur when cutting relatively thick special steel plates.

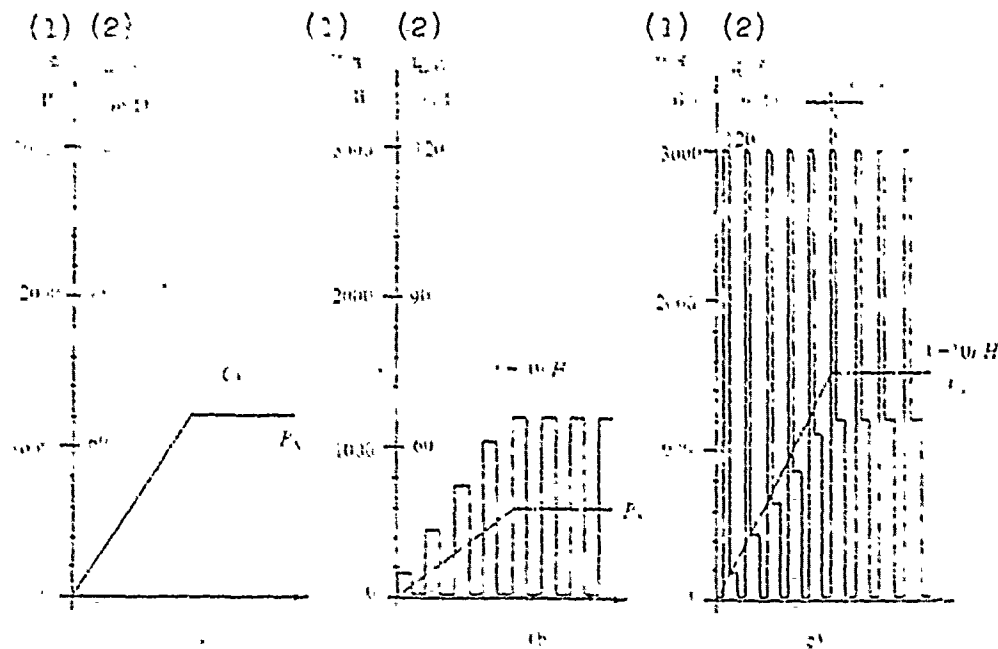


Fig. 5. Laser Emitting Modes for CO<sub>2</sub> Laser Device.  
 Legend: (a) Continuous type; (b) Conventional pulse;  
 (c) Giant pulse.  
 Key: (1) Power; (2) Electric current.

A conventional laser is one in which the laser beam is emitted at certain alternations of pulse width and pulse gap (see Fig. 5b). Each pulse peak value reaches the maximum power while emitting continuously; however, its mean power is lower than the average power of continuous emission. Hence, the cutting speed is also lower than the cutting speed at continuous emission. This mode can avoid local overheating of the metal material, thus it is adaptable to cutting and machining the heat-sensitive zone of structural steel plates. Generally, the density of emitting laser pulses is within 0.1 and 1 millisecond. The pulse gap varies within the range of 2 to 10 pulse widths according to the thickness and geometric shape of the worked material.

A giant pulse laser is a laser in which every pulse is considerably greater than the maximum power of continuous emission (referring to Fig. 5c); its mean power is even greater than the laser power at continuous emission. Compared with the conventional pulse, a giant pulse can be used to cut thicker materials; the cutting speed is also higher. The giant pulse is especially suitable to cut specialty steel plates.

#### IV. Positional Control of CO<sub>2</sub> Laser Machining

Laser cutting is realized through the relative displacement between the laser beam and the machined workpiece; its positional control often adopts the following types (see Fig. 6):

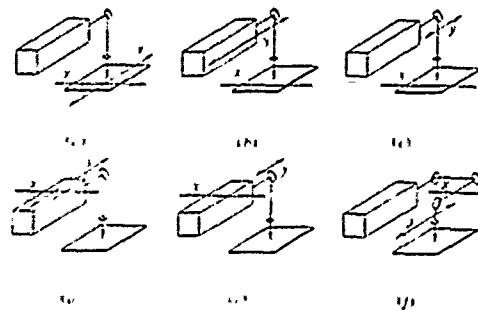


Fig. 6. Several Modes of Laser Machine Processing Tool Positional Control.

Legend: (a) Moving workpiece; (b) Moving workpiece and moving laser device; (c) Moving workpiece and deflecting lens; (d) Moving laser device; (e) Moving laser device and deflecting lens; (f) Moving deflection lens.

##### 1. Fixed laser optical axis with moving workpiece

In this system, the optical axis of the laser device is fixed while the workpiece is clamped, moving in two directions: X and Y. Or else, the workpiece moves with the work platform. This system is simple in design and has good stability in its optical path. Its layout is simple with high generalization and

high machining precision. Its shortcoming is an overly large work space requirement. When a thick plate is cut, the moving portion is large in mass. This system is used in the LC-644II/LC-667II and LCF-644 machine tools made by the Amada Corporation in Japan, as well as 180LW and 180LK machine tools made by the Trumpf Corporation in West Germany.

## 2. Moving optical axis of laser device with fixed workpiece

In this system, the workpiece is fixed. With a moving laser device or moving deflecting lens, the optical axis of the laser device moves in two directions: X and Y. In this system, no clamping is required for the workpiece; the material utilization rate is high, capable of machining a spatially shaped workpiece yet the work space occupied is relatively small. However, in this system very good stability is required for the integrated system composed of laser device, light guiding system, drive, deflecting lens and other machine components. This system is adopted in the Bystronic punching machine made by the Samro-Bystronic Corporation in Switzerland, and the model LCM-6510 made by the Amada Corporation in Japan.

## 3. Moving optical axis of laser device, and the workpiece

In this system, the workpiece moves in the X direction while the optical axis of the laser device moves in the Y direction. The optical axis of laser device can be made to move by moving the laser device or by moving the deflecting lens. The work space of this system represents only half that for the first system; in addition, the operating performance is better. This system is adopted in the model LCZ-644 laser cutting machine made by the Amada Corporation in Japan.

## V. Programming System of Laser Cutting

The programming system of laser cutting includes a microcomputer with screen display, a keyboard, a floppy disk drive, a wide line printer, a draft machine, a magnetic tape read in device, and a digitizer.

The laser outputted parameters, machining rate, geometric dimensions of parts and other data are inputted into the computer through a magnetic disk. For a complex shaped workpiece, its geometric shape data can also be directly inputted through a digitizer. The printer records all data inputted for examination and revision. The parts diagram is directly displayed on the screen for examination. The graphic compiling program includes input statements of some primitive geometric elements, such as straight line, circle, and rectangle, as well as operational descriptive statements of the machine, such as tool raising or lowering. The program statements can be randomly expanded by users. If errors are discovered after viewing the printout from the printer, correction can be made by revising the program.

To make adequate use of the slab material, the programming system includes a specialized optimization program, which can rotate the workpiece until an outline approximating a rectangle is formed, thus forming a new chessboard-type part for storage. For different workpieces with the same slab thickness, the formed chessboard type parts can be integrated and arranged onto a piece of slab material according to the required number of pieces. Fig. 7 indicates the steps of this process.

The above mentioned programming system is of a large model and independent. Generally, the programming system is not placed near the machine tool; instead, the control and operating information is transmitted through an fiber-optic lightguide to the laser machine tool. Some laser machine tools have a simple programmable microcomputer system. An operator can directly program parts at the machine tool with simple optimization. The

programming process is in the man-machine dialogue mode. However, the programming process and the production process of the machine tool cannot proceed simultaneously.

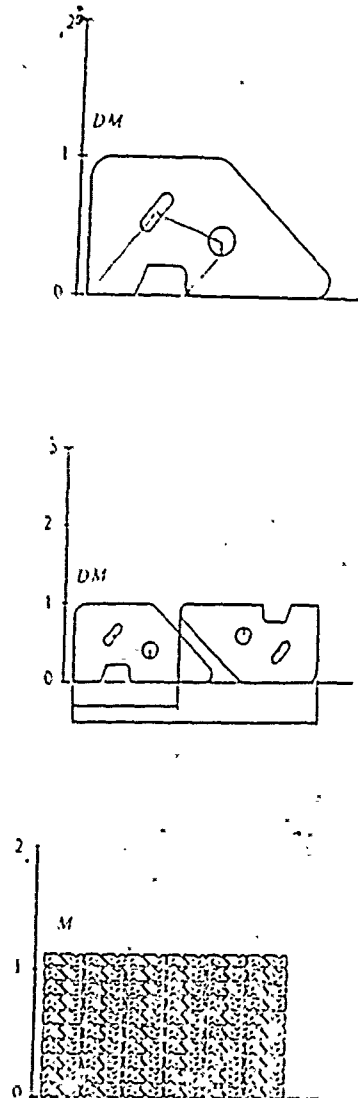


Fig. 7. Chessboard Type Arrangement Process of Laser Machining of Slab Material Parts.

At present, there are vigorous developments of laser cutting machines abroad; efforts are being made in systematization, multiple functions, serialization, generalization,



miniaturization, and flexibility. Simultaneous efforts are being made on upgrading the reliability of product quality and lowering the price of laser machine tools. In China, a limited number of factories imported laser cutting machines built abroad. One can be certain that laser cutting will be more extensively applied in China's slab material machining industry.

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